Pedological and some other soil-related activities within the Earth sciences discipline at the University of Waikato, Hamilton, New Zealand – the first 50 years (1969-2018)

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Photo on front cover:

Third-year pedology class (ERTH333-15A) at Radio Hut Rd site, Whakarewarewa Forest, during Rotorua field trip on 13 April, 2015, with David Lowe (holding sign). Photo courtesy of Felicity Leydon-Davis.

Abstract

We outline teaching and research activities relating to pedology and soil survey, and some other soil-related work involving geomechanics, both in New Zealand and Antarctica, carried out by staff and students in the Earth Sciences discipline at the University of Waikato for the 50-year period from 1969 to 2018. Key features include: (i) the insightful multi-disciplinary approach using a new Earth sciences' framework that was enacted at the outset by founding professor John D. McCraw and colleagues Michael J. Selby and Harry S. Gibbs in particular; (ii) the development of teaching and research strengths in pedology, especially involving tephra-derived soils and soil stratigraphy in the central North Island, and the concomitant advancement of prowessness in Quaternary tephrostratigraphy and tephrochronology; (iii) the development of expertise in slope studies and rock and soil mechanics (geomechanics, engineering geology), with specialist advancements regarding pyroclastic and associated reworked deposits and altered products; (iv) pathfinding research involving classical soil surveying and the subsequent growth of the use of GIS and geostatistical tools, which aided the eventual development of digital soil mapping beyond the university, and their application to a wide range of disciplines including geomorphology, sustainable plantation forestry, agriculture, and horticulture; (v) growth of expertise in multiple aspects of studies on wetlands (peatlands, lakes), and in environmental and carbon- and nitrogen-flux based research; (vi) pioneering and enduring research in Antarctica including soil surveying and studies on human impacts; and (vii) the successful development of an effective postgraduate school encompassing pedology, soil science, and geomechanics (amongst other disciplines). Waikato students have received around one half of the New Zealand Society of Soil Science annual awards for 'best masterate thesis', and around one third for 'best doctoral thesis' since 1976. In addition, staff and students in the department have led or contributed to many regional, national, and international conferences and associated field trips involving soils or Earth sciences, to the development of the "New Zealand Soil Classification", and to the discipline of pedology in many other ways including serving as editors and in professional societies.

1. Introduction

In this article, written in part to support a wider review being undertaken by Dr Philip Tonkin to synthesise the history of soil survey and selected aspects of soil conservation in New Zealand, we provide a short historical outline of the background and development of aspects of teaching and research activities relating to pedology and soil survey, and some other soil-related work including geomechanics, both in New Zealand and Antarctica, in the Earth Sciences discipline at the University of Waikato from 1969 to 2018. Of course, we provide a personal and selective view – we could not hope to cover every topic for the 50-year period, but numerous references should help to provide a flavour of the hard-won contributions and outcomes of the efforts by both staff and students. We acknowledge the great support received from technical and administrative staff that enabled the staff and students to undertake their research and other activities. We conclude by summarising some of the main features that may be seen to characterise the history.

2. Developing the new discipline of Earth sciences

The Department of Earth Sciences at the University of Waikato was established in 1970 within the newly-formed School of Science (Earth Sciences Staff, 1987; Nelson, 2000; Lowe, 2002a). Dr John McCraw, the foundation professor, and Michael J. Selby, senior lecturer, were both appointed in 1969 to enable them to prepare for the first student enrolments in 1970. John and Michael, soon to be joined by Harry Gibbs in 1970, played pivotal roles in the initial development of the department using a unique, integrative multi-disciplinary approach (Fig. 1). From 2006 the department operated as the Department of Earth and Ocean Sciences until April 2014. Then the subject 'Earth Sciences' became one of three alongside 'Biological Sciences' and 'Chemistry' within a revamped School of Science that continues today (Nelson et al., 2015).

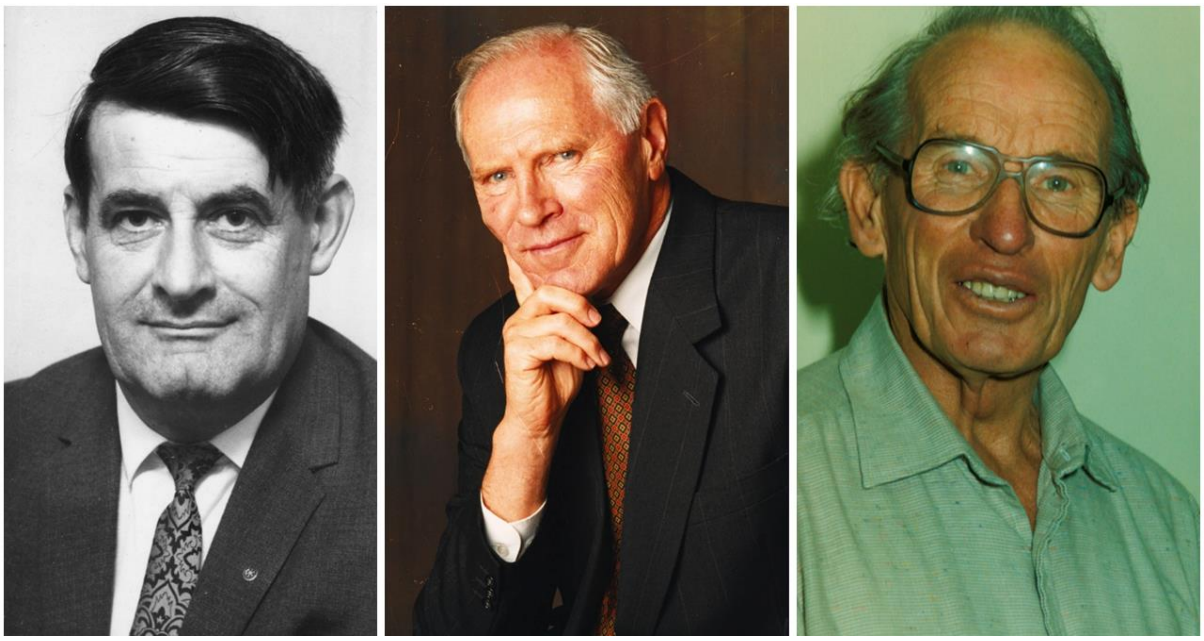

Fig. 1. From left, Professors John McCraw (in 1969), Michael Selby, and Harry Gibbs, the 'big three' who effectively founded the Department of Earth Sciences 1969-1970. Photos: University of Waikato.

Professor John McCraw, although trained as a geologist at the University of Otago, had spent the previous two decades as a pedologist and soil surveyor with the Soil Bureau of the New Zealand Department of Scientific and Industrial Research (DSIR). In this role he undertook pioneering work in Central Otago (e.g., McCraw, 1956, 1959, 1962, 1964, 1968) and then carried out the first soil survey of the Taylor Valley in the Dry Valleys area of the Ross Dependency, Antarctica (McCraw 1967a, 1967b). John later developed a life-long interest in the Hamilton Basin and its demonstrative soil-landscape relationships (e.g., McCraw, 1967c), and he returned to this topic (among many others) in his retirement years (e.g., McCraw, 2002a, 2011). A notable role undertaken by John McCraw in the late 1970s whilst head of department was his participation in the enquiry into the Abbotsford landslip disaster (Gallen et al., 1980). Professor McCraw retired in early 1988. Further details of his career and impact are provided by Nelson et al. (2015) and Tonkin et al. (2015).

In establishing the department, John had the assistance initially of Michael Selby, and then of Harry Gibbs, formerly the Chief Pedologist in Soil Bureau. Not surprisingly, pedology and geomorphology were included together with other core geoscience subjects in the early undergraduate and post-graduate Earth sciences' curriculum (McCraw, 2002b).

A geographer/geomorphologist trained at Oxford University, Michael, after teaching at Christ's College in Christchurch from 1960, was appointed a lecturer in physical geography in 1964 at the Waikato Branch of the University of Auckland in Hamilton. He then transferred to geography in the new University of Waikato in 1965 (the university having been founded in February 1964: Acorn, 2014) before being appointed to the new Department of Earth Sciences (1969). Michael wrote or edited seven text books, the first two being published in 1967 and 1971 (Selby, 1967a, 1971a), and a number of papers early on, thereby helping to establish the department's reputation and credibility in surface Earth sciences. In addition, Michael edited *Earth Science Journal*, based in Hamilton, for five years (1967-1971). He retired in 2002 as Deputy Vice Chancellor of the University of Waikato. Michael's career and legacy are reviewed by Nelson (2018).

As well as teaching (Fig. 2), a role to which he was well-suited, Harry Gibbs mentored and supervised a cohort of the earliest graduates undertaking pedology-based masterate research, and he wrote articles mainly about soils and land use (e.g., Gibbs, 1971a, 1974, 1981, 1982, 1983). Harry also published some of the soil survey work he had carried out largely prior to his appointment at Waikato (e.g., Gibbs, 1976; Northey and Gibbs, 1976), as did John McCraw (McCraw, 1974; McCraw and Bell, 1975). Professor Harry Gibbs retired in 1979, publishing an introductory textbook on New Zealand soils at around the same time (Gibbs, 1980).

Fig. 2. Harry Gibbs (far right) in his element with undergraduate students in the field looking at soils in the landscape (possibly at Hopuhopu Military Camp near Ngaruawahia) in c. 1973. Photo: R.R. Julian.

A distinctive character of the School of Science is the continuing Antarctic research programme that was initiated in the 1969-1970 field season with a party comprising Professor Alex T. Wilson (foundation professor of Chemistry and Dean of the School of Science), Michael Selby, Chris Hendy (Chris, working at DSIR at the time, was later appointed to a lectureship in chemistry at Waikato in 1971), and Jim Johnson (PhD student) (Harrowfield, 2007). Further details of the more recent Antarctic research programme relating to soil survey and associated studies are given below in section 10.

3. Pedology

The pedological capability of the department was enhanced with the appointments of Robert (Bob) F. Allbrook in 1975, David J. Lowe in 1979 (initially for 2.5 years, then continuously from 1984), Vicki G. Moon in 1984, Richard Chapman in 1986, and Megan R. Balks in 1988.

Dr Bob Allbrook was a graduate of Newcastle on Tyne University, and had spent a period as a soil surveyor in Nigeria before completing his doctorate (finalized after his appointment to the department) at the University of Malaya, where he studied the genesis of rice soils. His research at Waikato was mainly in the field of soil physics and included studies on the special properties of allophane and allophanic soils (Allbrook, 1983, 1985), and soil compaction and shrinkage (e.g., Cotching et al., 1979; Allbrook, 1980, 1986, 1992; Fredricksen, 1988; McLay et al., 1992). Bob, who retired in 1993, also was interested in the history of soil science in New Zealand (Allbrook, 1990, 1997) (Fig. 3).

Fig. 3. Staff of the Department of Earth Sciences, including Bob Allbrook (far left, second row) in 1987. Photo: University of Waikato.

Dr David Lowe (now professor) is a graduate of the University of Waikato where he teaches pedology and tephrochronology among his many interests that include soils derived from volcanic-ash (tephra), geochronology, Quaternary climate change, and geoarchaeology. Prior to his doctoral studies, David had short stints with Soil Bureau (Hamilton office), working on the Matamata County survey under the supervision of Gary Orbell, and preparing benzene in vacuum lines of the fledgling Waikato Radiocarbon Dating Laboratory within the Department of Chemistry. Dr Megan Balks, a graduate of Massey and Waikato universities, was a contract employee with Soil Bureau on soil surveys in Central Otago before moving to Waikato.

Pedology is included within the mix of undergraduate training together with other subjects relevant to teaching and research in soil geomorphology, Quaternary stratigraphy and chronology, soil and rock mechanics, and engineering geology. Numerous post-graduate studies have included aspects of pedology and soil survey amidst geological, environmental and palaeoecological focusses. In recent decades, a resource and environmental planning programme at Waikato was developed in conjunction with staff of the Department of Geography in the Faculty of Arts and Social Sciences. Dr Megan Balks developed and led the environmental sciences teaching curriculum for many years. Dr Vicki Moon teaches slope stability and engineering geology including geomorphology, this last subject becoming incorporated into a new GIS-based paper on spatial analysis in the Earth sciences, one of five year-2 level papers on offer in Earth sciences within a new curriculum that was executed from 2018 right across the university.

Dr Chris McLay, appointed to replace Bob Allbrook in 1994, taught soil science until he went to the Waikato Regional Council in 2002. Dr Louis Schipper (soil microbiology, carbon and nitrogen in soil-landscape systems) was appointed in 2005 and continues (as professor)

in the Earth sciences programme today, working closely with Associate Professor David Campbell (ecohydrology and climatology, especially of wetlands: section 9), and others, undertaking research in carbon fluxes and nutrient cycling, denitrification and nitrogen immobilisation, impacts of land use change, and microbial ecology, at scales ranging from molecular to landscape to global (e.g., Schipper et al., 2007, 2012, 2014a, 2014b, 2017).

Since the 1970s, numerous students have undertaken pedology-based thesis projects but the first to focus on soil survey *per se* was probably Dr Peter Singleton (Singleton, 1981), who later went on to write the seminal Ruakura soils bulletin, "A Window on the Waikato" (Singleton, 1991). Large-scale soil maps include those generated by former students Sarah Stiles (1998) and Kathryn McLauchlan (2001). Kathryn's work at her field site, located just north of Te Awamutu, followed, in a small way, in the footsteps of the influential soil survey of Waipa County undertaken by Grange et al. (1939), the first in New Zealand to use purpose-flown aerial photographs for soil mapping.

David Lowe carried out his first contract research, namely mapping soils on Steele's Farm at a scale of 1: 1250 near Hamilton Airport (Fig. 4; Lowe, 1979). The survey was commissioned by Bruce Willoughby who was leading a research programme at the Ministry of Agriculture and Fisheries, Hamilton, into grass grubs (brown beetle larvae, *Costelytra zealandica*). Bruce wanted to evaluate the effects of soil type on the occurrence and effectiveness of various treatments (e.g., East and Willoughby, 1980). David and some other graduates in the department provided occasional labour for Bruce by taking large numbers of ~15-cm-long cores (~10 cm diameter) of surface soil horizons in various parts of the central North Island from which counts of 'grubs' were then made.

Meanwhile, Tara Pryce mapped soils from both pedological and engineering viewpoints in her masterate thesis in the Flagstaff area of north Hamilton that was being developed for city expansion (Pryce, 1997), discovering a drained lake bed in the process. Richard Chapman examined soils on basaltic materials in the Raglan area with respect to cobalt levels and agriculture (Chapman, 1983), and later wrote a PhD thesis on soil physics (Chapman, 1992). Richard's PhD, interestingly, involved subsoiling trials on the physical properties of soils at Rugby Park (now Waikato Stadium), Hamilton, in preparation for the internationals held there during the Rugby World Cup of 1987 (Chapman and Allbrook, 1987).

The masterate study carried out by Warwick McDonald on pedality (soil structure) under pines and pasture (McDonald, 1985) led him eventually to high-level management roles involving soil and water resources, both in New Zealand and Australia, where he is currently director of CSIRO's Land and Water Research Management Program.

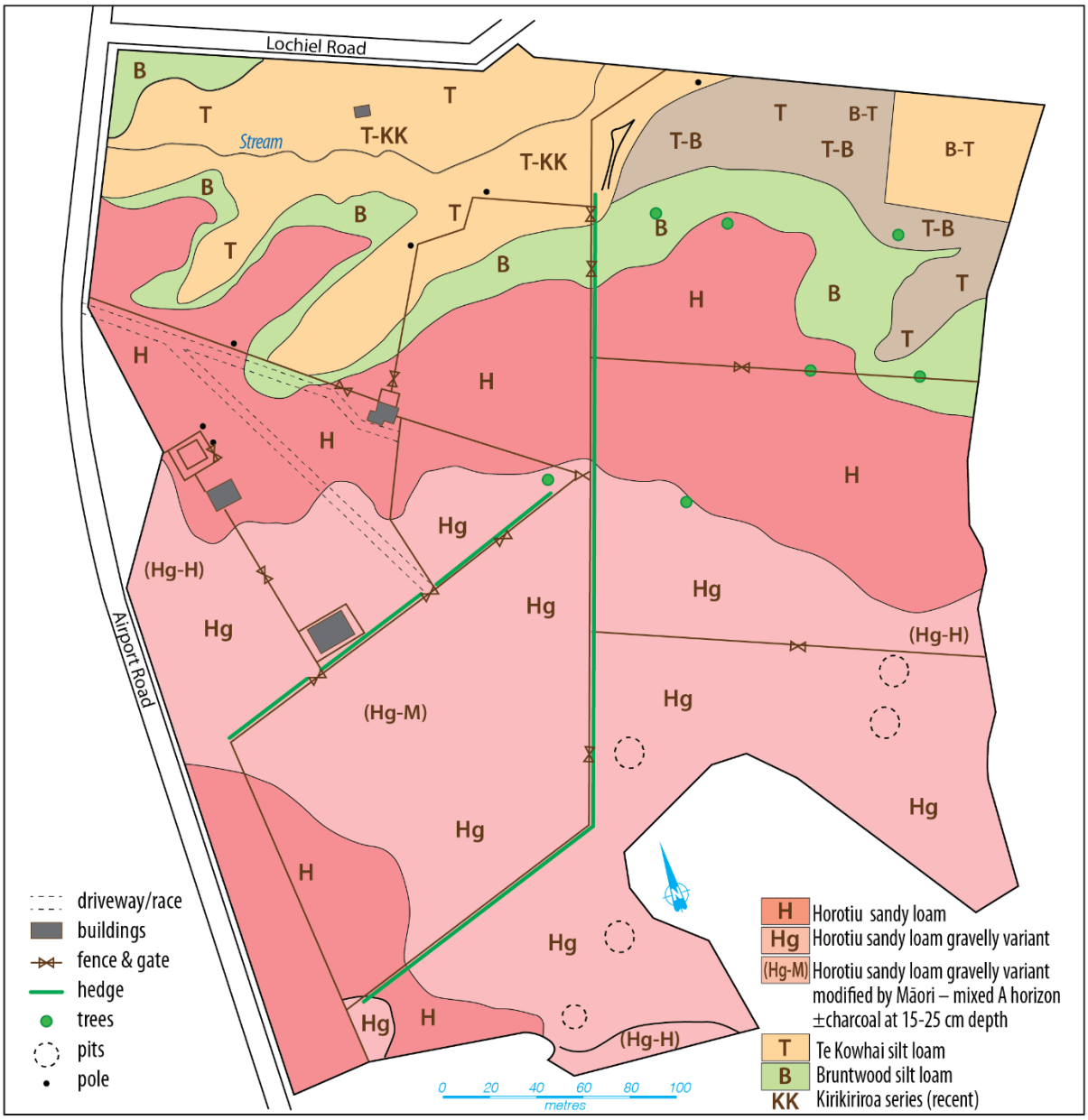

Fig. 4. Soil map made by David Lowe of Steele Farm, adjacent to Airport and Lochiel roads, Hamilton, originally at 1: 1250 (redrawn from Lowe, 1979, by cartographer Max Oulton).

5. Tephra studies and tephra-derived soils

David Lowe mapped distal tephra deposits in peat bogs and lake sediments, including the detection of what are now called cryptotephras (sparse glass shard and/or crystal concentrations preserved and 'hidden' in sediments or soils but insufficiently numerous, or too fine-grained, to be visible as a layer to the naked eye: Lowe, 2011) as part of his PhD research (Lowe et al., 1981; Lowe, 1985, 1988a, 1988b). Harry Gibbs and John McCraw, themselves building on the work of pioneers Les Grange, Norman Taylor, Colin Vucetich, and Alan Pullar (e.g., Grange, 1931; Taylor, 1932; Vucetich and Pullar, 1964; Pullar, 1967; see also reviews by Lowe, 1990a; Lowe et al., 2008a), had led the way with noteworthy papers

involving tephras and tephra-derived soils (Gibbs, 1968, 1971b; McCraw and Whitton, 1971; McCraw, 1975). But David followed perhaps more closely in the footsteps of Victoria University of Wellington graduate and geochemist, Dr Peter Hodder, and Waikato graduate, Dr Alan Hogg, in adopting laboratory-based mineralogical and geochemical techniques to supplement field observations. Peter Hodder investigated the origins of composite tephra-derived soils formed on the so-called "Tirau and Mairoa ashes" (Gibbs et al., 1982; Hodder and Wilson, 1976; Lowe, 1988a) in the Waikato region for his DPhil thesis at Waikato University, only the second awarded in the department (Hodder, 1974). Dr Hodder, a staff member in the department from 1980 until 1999, taught mainly geochemistry as well as environmental science and aspects of science history and philosophy. In the late 1970s, Dr Alan Hogg, now director of the Waikato Radiocarbon Dating Laboratory, investigated tephras and their distribution on the Coromandel Peninsula for his PhD (Hogg, 1979; Hogg and McCraw, 1983). Earlier he, along with Dr Tony Davoren, Ray Salter, Graham Shepherd, and Dr Joanne Horrocks, worked on the strongly weathered Kauroa and Hamilton ash sequences (Hogg, 1974; Davoren, 1976; Salter, 1979; Shepherd, 1984; Horrocks, 2000; see also Lowe et al., 2001). John Fry also undertook early studies on tephras (Fry, 1976).

The early work on tephras by David Lowe led him and colleagues and students to deeper research about the distribution, stratigraphy, nature (especially the unique clay mineralogy), and genesis of tephra-derived soils and paleosols in the North Island and also South Australia (e.g., Lowe, 1981, 1986, 1995; Hodder et al., 1990; Lowe and Nelson, 1983; Lowe and Green, 1992; Lowe and Percival, 1993; Lowe and Palmer, 2005; Takesako et al., 2010; Churchman and Lowe, 2012; McDaniel et al., 2012; Huang et al., 2016a, 2016b; Taylor et al., 2016). A foray into the powerful world of micromorphology with Lideweij (Liddy) Bakker, enrolled at Wageningen University and supervised by Dr Toine Jongmans, led to a publication on the development of properties of an age sequence of soils developed on tephra as seen through the microscope (Bakker et al., 1996a). That work by Liddy was presented at an international field conference on "Tephra, Loess, and Paleosols" organised by David Lowe on behalf of the International Union for Quaternary Research (INQUA) at the University of Waikato in February, 1994 (Lowe, 1996). The meeting was the first to be held involving three disciplines under the aegis of INQUA, and included two one-day regional field trips and a five-day post-conference field trip through North Island (Lowe, 1994). Liddy Bakker then embarked on her PhD project at Waikato on landscape evolution, which is described in section 8.

Many aspects of the understanding gained, including soil stratigraphy-based models for upbuilding pedogenesis (Lowe and Tonkin, 2010; Lowe et al., 2015), have been reported in North Island-based field trip guides associated with a series of national and international soil conferences since 2006 involving input from David Lowe and others (e.g., Lowe, 2006, 2008, 2010, 2016; Lowe et al., 2010, 2012, 2014) (Fig. 5). Nadia Laubscher (2014) undertook an exceptionally interesting MSc thesis project by investigating the exhumation of buried paleosols on Holocene tephras ("flipped soils") in the Galatea region of eastern Bay of Plenty that featured in the field trip documented by Lowe et al. (2014) (Fig. 6).

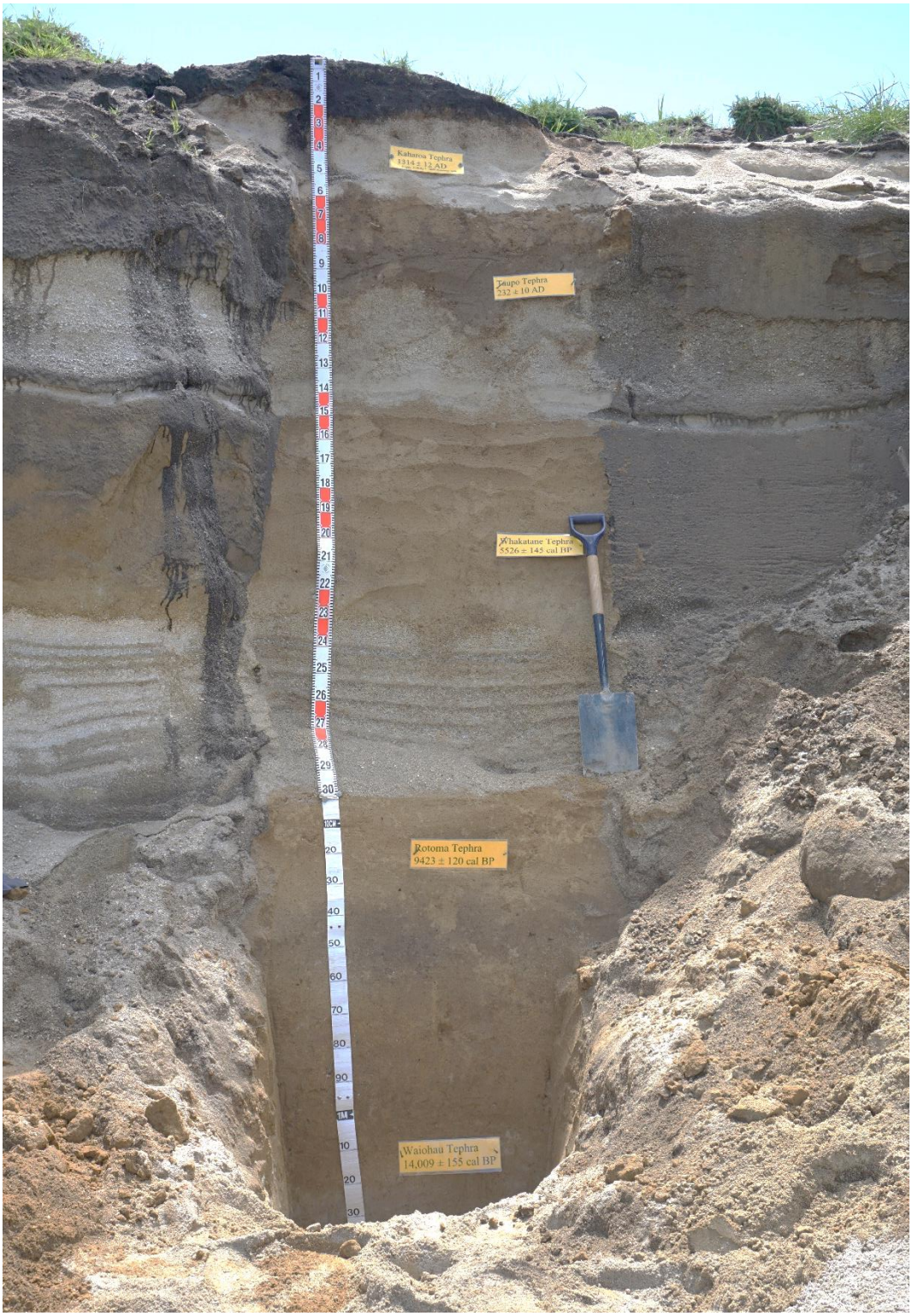

Fig. 5. Spectacular sequence of tephras and buried soil horizons at Eric Smeiths' quarry near the Whirinaki River, Murupara, in October 2014 prior to the group visit during the "Hot Volcanic Soils" field trip (Fig. 6). All the tephras except Taupo are from the Okataina Volcanic Centre; ages are from Lowe et al. (2013). Fluvial deposits (pebbles, cobbles) almost certainly underlie the Waiohau tephra (not visible). The modern Galatea soil, with Kaharoa tephra (deposited AD 1314 ± 12: Hogg et al., 2003) at the surface, is an Immature Orthic Pumice Soil, tephric, with pumice clasts > 2 mm ("rhyolite stones"), sandy, rapid (Hewitt, 2010; Webb and Lilburne, 2011). In "Soil Taxonomy" it is a Typic Udivitrand, pumiceous, glassy, mesic (Soil Survey Staff, 2014) (Lowe et al., 2014). Photo: D.J. Lowe.

Fig. 6. Participants on the "Hot Volcanic Soils" field trip led by David Lowe, Megan Balks, and Nadia Laubscher, on Eric Smeith's farm on Whirinaki Road near Murupara, eastern Bay of Plenty, on 2 December, 2014. The trip to Taupo and the Galatea depression was run as part of the NZSSS national soils conference held in Hamilton from 1-4 December that year. Photo: D.J. Lowe.

In conjunction with tephra work, Joanne Macky (1997) and then Kerri Lanigan (2012) mapped subsurface tephric loess in the Tapapa-Tauranga and Rotorua areas, respectively, for their masterate theses. Previously, Glenn Wigley mapped in the Te Puke lowlands and used tephrochronology to date dunes, peats, and associated soils (Wigley, 1990; Lowe et al., 1992).

David Lowe, Alan Hogg and others also worked on the characterisation and dating of widespread tephras, which helped provide useful marker beds or isochrons for soil-related studies, for Quaternary paleoenvironmental studies, and for volcanological, archaeological, and historical research in New Zealand and elsewhere (e.g., Hogg et al., 1987, 2003, 2012; Lowe, 1988b, 1990a; Lowe et al., 1998, 2000, 2008b, 2011, 2013, 2017a; Newnham et al., 1998, 1999, 2018; Lane e al., 2017).

David worked with Warren Gumbley and others on soils that had been modified by early Maori in the Waikato region to grow kumara (Gumbley et al., 2004) (see also Fig. 16 below), an interest shared by John McCraw (McCraw, 2011), and on the impact of volcanism on early Maori (Lowe et al., 2002).

6. New Zealand Soil Classification

David Lowe and Megan Balks, together with Bob Allbrook in the late 1980s-early 1990s, contributed to the development of the "New Zealand Soil Classification" (NZSC) system during its construction by Dr Allan Hewitt and publication of the first edition (1992a, 1992b, 1993) (NZSC is now in its third edition: Hewitt, 2010). They tested early versions of NZSC (e.g.,

Hewitt, 1987) and also aspects of the "Soil Description Handbook" (Milne et al., 1995), on pedology field trips with students including during annual Northland and Waikato excursions (Fig. 7), and provided feedback to authors that did result in some improvements. Lowe and Allbrook also contributed to discussions on defining soil series (Allbrook, 1989; Clayden et al., 1989; Lowe, 1989). Reviews of NZSC and companion publications relating to soil survey (Clayden and Hewitt, 1989; Milne et al., 1995) were published by Lowe (1990b, 1992) and Lowe and Balks (1996).

Fig. 7. Dr Haydon Jones commenting on the properties of the photogenic Whangaripo soil (Mottled Yellow Ultic Soil in NZSC or Typic Hapludult in "Soil Taxonomy"), complete with red-weathered lower subsoil, near Warkworth, Northand, during a third-year pedology field trip in 2006.

7. Geomechanics and slope stability

Michael Selby initially examined slopes and landslides on the ash-mantled greywacke hills in the Whitehall area near Cambridge. In one of his earliest papers, he argued that non-periodic mass movement, rather than stream erosion as invoked by Sir Charles Cotton, was largely responsible for the origin of the slopes and boulder fields in the area (Selby 1966, 1967b). Moreover, Michael pointed out that some of the mass movement (such as landsliding) could be dated approximately using the presence of tephra deposits in or on the deposits, i.e., using tephrochronology, a method he employed in later studies with tephra 'guru', Dr Alan Pullar (Pullar and Selby, 1971; Selby et al., 1971). Michael then worked on the erosion of pumice soils in the Taupo region in a characteristically innovative mix of specially designed field and laboratory experiments and (at the time) novel computer-based factor analysis (e.g., Selby, 1970a, 1970b, 1972, 1973; Selby and Hosking, 1971, 1973). Michael's DPhil thesis (Selby, 1971b) was the first to be completed in the Department of Earth Sciences and one of the first three doctorates to be awarded by the University of Waikato on 2 March 1972 (Nelson, 2018). Michael supervised Robin Palmer's masterate thesis on variations in soils on slopes at Whatawhata where ash overlies weathered greywacke (Palmer, 1974). Robin went on to Massey University, where he mapped the soils of Egmont and part Taranaki counties 1975-1977 (Palmer et al., 1981), and then to Soil Bureau.

With Dr Vicki Moon, Michael Selby developed soil and rock geomechanics, and subsequently an engineering geology programme, which potentially could expand with the advent of civil engineering in the Faculty of Science and Engineering from 2017. Engineering geology became an important strength within the Department of Earth Sciences from the 1980s-1990s, leading to many students subsequently gaining livelihoods in the field following masterate thesis projects in the discipline. Michael developed simple portable equipment to assess the mass strength of rocks and, from this and a number of other easily assessed parameters, he established a 'Rock Mass Strength Index' that has been adopted internationally, not only by geologists and geomorphologists, but also by engineers (Selby, 1980, 1982). The second edition of Michael's textbook "Hillslope Materials and Processes" (Selby 1993), which brilliantly integrates geomorphology with engineering geology, was named in 2005 as one of the 10 'classic' books of geomorphology and its author as one of the 20 most-cited geomorphologists in the English language (Doyle and Julian, 2005). Another book, "Landforms of New Zealand" (Soons and Selby, 1992), comprised the first synthesis of New Zealand geomorphology and landscapes since the seminal volumes of Sir Charles Cotton of the early- to middle-20th Century (e.g., Cotton, 1942) and has only recently been superseded in part by books published by Shulmeister (2017) and Williams (2017).

Vicki Moon has continued to lead research into mass movement and slope stability including landsliding and the role of sensitivity, especially in pyroclastic (tephra) deposits and their reworked and weathered derivatives (such as occur in the Tauranga area), mainly in northern North Island (e.g., Moon et al., 2015a, 2015b, 2017; Kluger et al., 2017; Robertson et al., 2017) (Fig. 8). These and associated studies on the impact of mass movement on forestry and farming (e.g., Heaphy et al., 2014; Noyes et al., 2015), and unexpected discoveries along the way (e.g., Cunningham et al., 2016; Lowe and Churchman, 2016), have been important topics for research over the past few decades at Waikato.

Fig. 8. Landslide at McDonnell Street in Omokoroa, Tauranga, close to the well-studied Bramley Drive landslide (e.g., see Moon et al., 2015b; Kluger et al., 2017). The McDonnel Street slide took place overnight 5-6 April, 2017, during the tail end of Cyclone Debbie. The Bramley Drive slide occurred on 9 August 1979 and was reactivated in May 2011 and in April and August 2012. Photo: V.G. Moon

With the discovery of numerous faults in the Hamilton area in 2015 (Moon and de Lange, 2017; Spinardi et al., 2017), the subject of paleoliquefaction is being investigated at present (e.g., Kleyburg et al., 2015; McKay et al., 2017).

8. GIS and pedometrics

The advent of geographic information systems (GIS) led to new work by Dr Lideweij Bakker on the Mamaku Plateau that involved developing a landform classification using a digital elevation model (Bakker et al., 1996b), and processes associated with the development of welded ignimbritic landscapes (Bakker, 1997) pertaining to the nine-unit landsurface model that was originally developed in the central Waikato region by Dalrymple et al. (1968). At around the same time, soil-landscape modelling was taking off (e.g., Webb, 1994) and two students, Dr Haydon Jones and Dr David Palmer, embarked on projects involving GIS and soil-landscape modelling at a range of scales relating primarily to requirements for plantation forestry. Scion staff, including Dr Tim Payn, Dr Mark Kimberley, and Barbara Höck, were key players in helping to support this research. Haydon Jones initially worked in Southland, aided greatly by Dr Ron Taskey (California Polytechnic State University), to develop a soil-landscape model using a land systems approach and to predict soil property variability in the Longwood

Forest (a contract for Rayonier) (Jones et al., 1997; Jones, 1998). Haydon then switched to Northland to undertake his PhD work on developing soil-landscape models for the southern Mahurangi Forest near Warkworth that additionally included a study to evaluate the impact of forest harvesting on the efficacy of the modelling to predict key soil properties (Jones et al., 2000; Jones, 2004). Haydon's field work in Northland was supported in part by Wim Rijkse (Landcare Research; see Lowe et al., 2017b) and Dr Toine Jongmans (Wageningen University).

David Palmer worked initially on Tihoi soils (Podzol Soils) on the Mamaku Plateau to evaluate their ability to sustain long-term radiata pine productivity, and he undertook spatial analysis using geostatistics (pedometrics) to compare soils under native forest with those under one and two pine rotations (Palmer et al., 2005) (Fig. 9). David then carried out his PhD project on spatial modelling of radiata pine productivity at the national extent, integrating multiple terrain attributes and surfaces, water-balance models, and soil and other data in macro-catchments across North and South islands and related them to pine-tree growth and its drivers (Palmer, 2008; Palmer et al., 2009a, 2009b, 2009c, 2010; Watt et al., 2010).

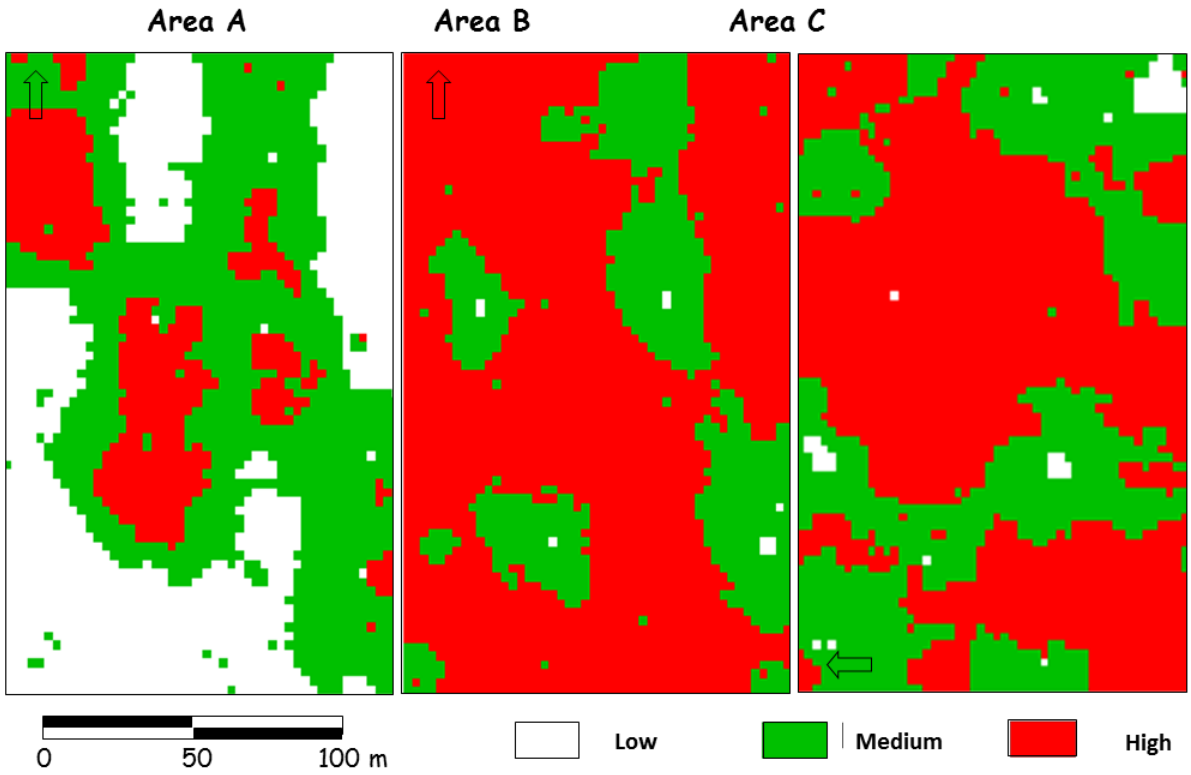

Fig. 9. Maps of P 'releasing capacity' of Tihoi soils (Humose Orthic Podzol Soils in NZSC or Andic Haplohumods in "Soil Taxonomy") on ~1800-year old Taupo ignimbrite (soft pumice) deposited AD 232 ± 10 (Hogg et al., 2012) at three sites on Mamaku Plateau (~10 km east of Tokoroa) with different forest histories: ***Area A***, Tihoi soils in original state under native forest; ***Area B***, Tihoi soils growing their first crop of *Pinus radiata* (24 years' growth in 2001 at the time of sampling); and ***Area C***, Tihoi soils that had grown one harvested crop of *P. radiata* and currently growing a second crop of radiata (4 years' growth in year 2001). The maps were derived by inverse-distance weighting as part of a pedometric project undertaken by David Palmer for his masterate thesis (from Palmer et al., 2005, p. 150).

More recently, Sharn Hainsworth undertook a mapping project for his masterate thesis involving both classical and digital soil mapping and land use capability (LUC) surveys on the Ruataniwha Plains in Hawke's Bay (Hainsworth, 2012). He is refining and developing further digital mapping techniques for hilly terrrains whilst working for Landcare Research. James Linehan (2015) contributed to this research, employing soil-landscape modelling to map the greywacke foothills of southern Hawke's Bay. Sharn Hainsworth, Dr Malcom McLeod, and a number of other former Waikato students including Dr Scott Fraser, Dr David Palmer (until early 2017), Nadia Laubscher (from 2017), and Jonno Rau (from 2018) are engaged, or have been engaged, in Landcare Research's "Smap" soil survey programme

9. Peatlands and peat lakes

Waikato University carried out a national survey of peat resources for the National Water and Soil Conservation Authority in 1975. This survey, coordinated by John McCraw, was led by Dr Tony Davoren (a Waikato MSc graduate) and was carried out by staff and students of the Earth Sciences and Biological Sciences departments (Davoren, 1978). Many detailed peatland-based research studies, especially on the large, unaltered restiad bog in the Hauraki lowlands, Kopouatai bog, and on Moanatuatua bog and the Waikato peat lakes, have since been carried out over the past 40 years by staff and students in the Earth sciences and other disciplines. Their research includes collaborative work on vegetation (present and past), stratigraphy (including tephrostratigraphy), palaeoenvironmental reconstructions (from palynology and plant macrofossils), ecohydrological functioning, and carbon exchange (e.g., Green and Lowe, 1985; Lowe and Hogg, 1986; Newnham et al., 1989, 1995; de Lange and Lowe, 1990; Hodder et al., 1991; Campbell et al., 1997; de Lange et al., 1999; Lowe et al., 1999; Thompson et al., 1999; Newnham and Lowe, 2000; Clarkson et al., 2004, 2009; Nieveen and Schipper, 2005; Gehrels et al., 2006, 2008; Goodrich et al., 2015, 2017). Degradation and shrinkage (subsidence) of peatlands through time have also been investigated (e.g., Pronger et al., 2014), along with their potential restoration (e.g., Clarkson et al., 1999).

One of the so-called peat lakes in the central Waikato region, Lake Maratoto, lies about 10 km south of Hamilton and is c. 22,000 years old (Fig. 10). The formalised boundary between the Pleistocene and the Holocene, defined in a Greenland ice core, is defined for Australasia in the sediments of Lake Maratoto (Walker et al., 2009), marked by a thin but distinctive Egmont-derived tephra layer, Konini bed-b, dated at c. 11,800 years old. The proposal for the tephra-bearing Lake Maratoto sediments to become the archive for the Australasian parastratotype for the base of the Holocene was made by Professor Rewi Newnham (Victoria University of Wellington) and David Lowe. Barrell et al. (2013) further suggested that the upper sediments of the lake provide a prospective New Zealand type section for the Holocene interglacial in New Zealand. Earlier, Lowe (1985, 1988a) and Green and Lowe (1985) used ground-penetrating radar, and multiple cores from the lake and adjacent peats, to map tephra layers in the peat and lacustrine deposits in and around Maratoto.

Fig. 10. Internationally important Lake Maratoto near Hamilton in which the Pleistocene-Holocene boundary for Australasia is defined as one of five global auxiliary sites (parastratotypes) for this transition. The lake is hemmed in to the west (top of image) by thick peat of the Rukuhia bog on top of volcanogenic alluvium (Hinuera Formation) (Green and Lowe, 1985). Photo: D.J. Lowe.

10. Soil survey in the Ross Dependency (Ross Sea region) of Antarctica

Prof John McCraw (along with Dr Graeme Claridge) undertook the first soil-focussed expedition to Antarctica in 1959-60 (commemorated 50 years later with a special anniversary event in the department, organised by Megan Balks, in November, 2009: Fig. 11). This trip resulted in the first soil mapping in Antarctica (noted earlier) with John's pioneering soil map of the Taylor Valley published in 1967 (McCraw, 1967a, 1967b). About ten years later, Michael Selby together with Peter Kamp, David Lowe, and Craig Law, undertook a sledging expedition to the Darwin Mountains area in the 1978-79 field season (Fig. 12). This trip was the first from Waikato to venture onto ice and beyond the 'tropical' Dry Valleys region. As well as mapping the hard-rock geology, Peter and David also mapped glacial deposits in the northern Britannia Range and correlated these with equivalent units in the Dry Valleys, thereby providing approximate ages for the moraines and soils exposed on them in the northern Britannia Range area (Kamp and Lowe, 1982). The discovery of the Derrick Peak iron meteorites (Clarke, 1982) was a highlight of the trip, and the party also had the honour of naming McCraw Glacier and Mount Selby in the mapping area to commemorate the leadership and contributions to Earth sciences of these two founding staff in the School of Science at the University of Waikato.

Fig. 11. John McCraw (left) and Graeme Claridge in November, 2009, at the University of Waikato's 50th anniversary celebration of their pioneering soil surveying trip to Antarctica in 1959-60. Photo: D.J. Lowe.

Fig. 12. Waikato University's field party on Darwin Glacier in November, 1978, before being lifted into the northern Britannia Range. From left, Peter Kamp, Craig Law, Michael Selby, and David Lowe. Photo: D.J. Lowe.

Building on the extensive Antarctic soil work of Drs Iain Campbell and Graeme Claridge (both Soil Bureau, DSIR), Dr Megan Balks led the next efforts to undertake soil mapping of Antarctica which were undertaken in collaboration with Landcare Research as part of a global initiative with the ANTPAS (Antarctic Permafrost and Soil) group. The major outcomes of this work were the detailed mapping of the Wright Valley undertaken by Malcolm McLeod for his PhD (McLeod et al., 2008, 2009; McLeod, 2012). A detailed map of the Cape Hallett area was undertaken by Erica Hofstee as an MSc project (Hofstee, 2006; Hofstee et al., 2006a). Three 'windows' in the deep south Beardmore Glacier area were mapped by Josh Scarrow as part of his MSc thesis (Scarrow, 2013; Scarrow et al., 2014), and a composite overall map of the wider region was developed by McLeod, Balks, and American colleague Prof James Bockheim (University of Wisconsin – Madison) (Balks et al., 2008) as well as an elucidation of the soil-landscape relationships (Balks et al*.,* 2013; Balks and O'Neill, 2016). In addition, Bockheim and Balks (2008) edited a special Antarctic issue of *Geoderma*. A long-term soil climate monitoring programme, established in 1999, has provided the best available data in Antarctica related to depth of permafrost and between-season variability in Antarctic soil climate. The research on the data was undertaken by a series of MSc students (Wall, 2004; Adlam, 2009; Adlam et al., 2010; Seybold et al., 2010; Goddard 2013; Guglielmin et al., 2011; A. Carshalton, in progress). The active layer monitoring is also part of wider global permafrost monitoring efforts (e.g., Viera et al., 2010).

A major theme of much Antarctic work has related to human impacts on the soil environment. This commenced under the farsighted initiative of Iain Campbell who led three expeditions with Graeme Claridge and Megan Balks in 1990–1992 with a focus on impacts of soil disturbance on the landscape and permafrost. These trips culminated in the development of the visual soil assessment method (VSA) for evaluating Antarctic soil surface disturbances

(Campbell et al., 1993). The VSA method continues to be widely used across the Antarctic continent as a simple and practical way of monitoring human impacts on the terrestrial environment. During this period some pioneering work was also undertaken to determine the ice content of permafrost and the effects of disturbance on permafrost ice content and potential for surface subsidence following disturbance (Campbell et al., 1994, 1998), along with work on metal contaminants in Antarctic soils (Claridge et al., 1995, 1999).

That research led on to a 20-year collaboration between Megan Balks and Dr Jackie Aislabie of Landcare Research (Fig. 13) which focussed firstly on impacts of oil spills on the Antarctic terrestrial environment (Aislabie et al., 1999, 2004, 2006, Balks et al., 2002, Holmes 2002), and then widened to a range of contaminants and physical disturbance activities and soil studies (e.g., Shanhun, 2005; Hofstee et al., 2006b). Tanya O'Neill undertook her PhD studying the effects of tourist activities on the Antarctic environment (O'Neill, 2013; O'Neill et al., 2012, 2013a, 2013b, 2014, 2015). Her research culminated in studies that focussed on soil recovery following disturbance (O'Neill et al., 2013b). The Antarctic environmental work also led to contributions to the Ross Sea region "State of the Environment" report (Campbell and Balks, 2001) and the Antarctic section of the FAO "Status of World Soils" report (Balks, 2015).

Fig. 13. Megan Balks and Jackie Aislabie at Cape Hallet, Ross Sea region, Antarctica, in the 2004-05 field season. Photo: M.R. Balks.

11. Teaching pedology, further contributions to the discipline, and awards

Since 2005, the soil science teaching at Waikato has been carried out mainly by David Lowe, Louis Schipper, and Megan Balks (Fig. 14). Each (along with Prof John McCraw) is a fellow of New Zealand Society of Soil Science (NZSSS) and each in addition has presented the annual N.H. Taylor Memorial Lecture of NZSSS (McCraw, 1979; Lowe, 2002b; Balks, 2009; Schipper,

2016). All three contributed recently to a global paper on teaching soil science by Hartemink et al. (2014). Their efforts were enhanced in 2014 by the appointment of Dr Tanya O'Neill as a teaching fellow (Fig. 14).

In 2011, David Lowe, with help from Louis Schipper and Megan Balks, developed a new graduate paper, "Land and Soil Evaluation". Part of the paper requires students to undertake farm-scale soil surveying and land-use capability (LUC) mapping on part of the Tokanui Research Farm to the south of Te Awamutu (using Manderson et al., 2007; Lynn et al., 2009) (Fig. 15). The exercise, developed with valued advice from Sharn Hainsworth, Gary Orbell, and Dr Richard Chapman (who left Waikato University in 2000 to form his consultancy "Soil and Land Evaluation"), is proving popular and worthwhile. Important contributions from Dr Debbie Care (Agritech) and Dr David Houlbrooke (AgResearch) complement the mapping and an exercise on N budgeting (Louis Schipper); work on soil quality, including reference to the "Soils 500" project (Louis Schipper, Tanya O'Neill, and Dr Brian Stevenson, Landcare Research) rounds out the paper.

Megan Balks completed a general introductory text book about the world of soils in 2016 (Balks and Zabowski, 2016). She 'retired' in February 2018 but continues as an Adjunct Senior Research Fellow in the School of Science at Waikato, remaining active in student supervision and undertaking writing work and other tasks that support soil science nationally and internationally.

Fig. 14. Staff of Department of Earth and Ocean Sciences at the University of Waikato on ~31 March 2014. The five chairs of the department who succeeded John McCraw (founding head of department, in front row, second from the end at far right) are present: Cam Nelson (8 years 1988-1995), Roger Briggs (6 years 1996-2001), Megan Balks (4 years 2002-2006), Dave Campbell (6 years 2006-2012), and David Lowe (2 years 2012-2014). The department was amalgamated into a new School of Science from 1 April 2014. Photo: N. Guest and M. Oulton.

Back row (left to right): Dean Sandwell, Karin Bryan, Shaun Barker, Peter Kamp, Aaron Wall, Janine Ryburn, Cam Nelson, Elizabeth Brodie, David Lowe, Earl Bardsley, Willem de Lange, Julia Mullarney, Hazel Needham, Chris Morcom, Roger Briggs, Renat Radosinsky, Dirk Immenga, Martin Danisik.

Front and middle rows (left to right): Tanya O'Neill, Louis Schipper, Xu Ganqing, James Neale, Annette Rodgers, Rochelle Hansen, Megan Balks, Adrian Pittari, Vicki Moon, Dave Campbell, Sydney Wright, Kirsty Vincent, John McCraw, Bethany Fox.

Another contribution by these staff to soil science has been to organise and host the biennial Waikato-Bay of Plenty regional soils conference in early December at Waikato University, the first being held in 2011 (Schipper and Lowe, 2012). These one-day meetings cover a range of topics including pedology and attract around 60 participants (Fig. 17), with the fourth meeting held on 5 December, 2017 (this date [5 December] is designated World Soils Day annually).

Staff and students have also contributed to national and international conferences over the years (some noted above), including the national soils conference of NZSSS that was hosted on the University of Waikato campus in 2014. Balks and Schipper have served as elected representatives on the Council of NZSSS, and Lowe has served with the tephra commission of the International Union for Quaternary Research (INQUA). They have been editors or associate editors of soil-related scientific journals such as *Geoderma* and *Soil Science Society of America Journal,* and also Quaternary journals including *Quaternary International* and *Quaternary Geochronology.* All have written regularly for *New Zealand Soil News.*

Fig. 15. The next generation: graduate students of the "Land and Soil Evaluation" masterate class on 9 March, 2018, on Tokanui Farm near Te Awamutu. Photo: D.J. Lowe.

A point of great pride to the soil-science related academic staff at Waikato is the success of their graduates on the national stage, especially in winning NZSSS awards. Twenty graduates from the University of Waikato have won the Sir Theodore Rigg Award for best masterate thesis, 49% of the awards that have been made since the award was established in 1976. Another 14 have received the Dr Morice Fieldes Award for best doctoral thesis, 34% of the awards since 1976. Six Waikato graduates since 1993 have benefitted from being awarded the Bert Quin Bursary of NZSSS.

Louis Schipper was awarded the society's M.L. Leamy Award in 2014 for 'best publication in soil science for the past three years', primarily for his paper "Thermodynamic theory explains the temperature optima of soil microbial processes and high Q10 values at low temperatures" (Schipper et al., 2014a). Louis was elected a Fellow of the Soil Science Society of America (2009). David Lowe, in contrast, won the McKay Hammer Award of the Geoscience Society of New Zealand in 2011 for the 'most meritorious papers in geology in New Zealand in the previous three years' for two tephra-based papers, Lowe et al. (2008b) and Lowe (2011). He was elected a Fellow of the Royal Society of New Zealand in 2010.

Fig. 16. 'Puke' or small mounds for growing kumara in the unique early Maori garden (called Te Parapara) at the Hamilton Gardens, on the lowest terrace underlain by Taupo Pumice Alluvium near the Waikato River, Hamilton, during the NZSSS conference held in December 2014. Participants in the background are being spoken to by the garden's designer, Wiremu Puke. Photo: D.J. Lowe.

12. Conclusions

Pedological and other soil-related teaching and research activities in the Department of Earth Sciences (and subsequent designations of the Earth sciences' group) at the University of Waikato for a 50-year period from 1969 to 2018 have been innovative and successful, and arguably have led to the development of special expertise in various disciplines, often collaboratively, within the Earth sciences. Key features of the 50-year history include:

(i) the new, integrative Earth sciences framework that was established by founding professor John McCraw and enacted initially by him and colleagues (professors Michael Selby and Harry Gibbs) and subsequent staff;

(ii) the development of teaching and research strengths in pedology, especially involving soil stratigraphy and tephra-derived soils in the central North Island and their unique mineralogical and physico-chemical properties, and the concomitant advancement of expertise in Quaternary tephrostratigraphy and tephrochronology;

(iii) the development of studies in rock and soil mechanics and engineering geology, and on slopes and slope stability, with specialist expertise regarding pyroclastic and associated deposits, especially weathered materials;

(iv) pathfinding research involving classical soil surveying and the subsequent growth of the use of GIS and geostatistical tools, aiding the later development of digital soil mapping beyond the university, and application to a wide range of disciplines including geomorphology, sustainable plantation forestry, and agriculture;

(v) pioneering and sustained research in Antarctica including soil surveying at a range of scales along with studies on human impacts;

(vi) a national peat survey, and many wide-ranging studies on peatlands, as well as environmental and carbon- and nitrogen-based research at multiple scales; and

(vii) the successful development of a strong postgraduate school involving pedology, soil science, and geomechanics disciplines. Notably, Waikato students have received around one half and one third of the NZSSS awards for 'best masterate thesis' and 'best doctoral thesis', respectively, since 1976.

Staff have contributed to the development of the "New Zealand Soil Classification", and staff and students in the department have convened or contributed to regional, national, and international conferences, including on behalf of NZSSS, and led many field trips, involving soils, pedology, tephras, or Earth sciences more generally. They have contributed in various other ways to the discipline of soil science. Four staff members have been awarded fellowships and the N.H. Taylor Memorial Lecture Award of NZSSS.

Fig. 17. Some of the participants in the biennial regional soils conference, 'Wai-BOP Soils 2013', hosted by the Department of Earth and Ocean Sciences, on World Soils Day (5 December), 2013. Photo: D.J. Lowe.

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We thank Dr Phil Tonkin for inspiring this review. Phil's very substantial efforts in recording and publishing the history of soil science in its widest sense in New Zealand, and writing about its many practitioners, are priceless. All the staff and students who have been part of, and contributed to, the Earth sciences revolution at Waikato over the past 50 years are acknowledged and thanked. They have won respect and friends. Many graduates and postgraduates have gone on to fulfilling careers including leadership roles, contributing substantially to the advancement and dissemination of knowledge and to the development of New Zealand and other countries – a fitting legacy for founder Prof John McCraw and his staff and many others who have given much to provide the opportunities for Earth sciences to grow and flourish at the University of Waikato in Hamilton. *Bonne chance* to all those involved for the next 50 years!

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